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13. ABSTRACT *(Maximum 200 words)*

The results of this grant are: (a) development and analysis of new methods and methodologies for solving PDEs on parallel machines, (b) development of mapping strategies of PDE computations to parallel machines, (c) development of knowledge bases for parallel PDE solvers, (d) development of a facility for visualization, collection and analysis of performance data, (e) development of a machine independent object-oriented knowledge interface for specifying PDE computations and solvers, and (f) performance evaluation of PDE solvers on Intel and NCUBE hypercube machines. The feasibility of the proposed ideas was established and usable prototypes have been developed.

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FINAL REPORT FOR AFOSR CONTRACT 88-0243
Parallel Methods and Systems for Solving Partial Differential Equations

1 Aug 88 - 30 Apr 91

In this report we list the personnel that worked under the previous AFOSR grant, the publications completed and describe the states of various projects. The results under this contract include:

(a) development and analysis of new methods and methodologies for solving PDEs on parallel machines,

(b) development of mapping strategies of PDE computations to parallel machines,

(c) development of knowledge bases for parallel PDE solvers,

(d) development of a facility for visualization, collection and analysis of performance data,

(e) development of a machine independent object-oriented knowledge interface for specifying PDE computations and solvers, and

(f) performance evaluation of PDE solvers on Intel and NCUBE hypercube machines.

We have demonstrated the feasibility of our proposed ideas and have developed usable prototypes.

Personnel

Work on this grant has involved the following people:

John R. Rice* (Co-PI)	Professor of Computer Science
Elias N. Houstis* (Co-PI)	Professor of Computer Science
Apostolos Hadjidimos*	Visiting Professor of Computer Science
Catherine E. Houstis	Visiting Assoc Professor of Computer Science
Manolis Vavalis*	Postdoc
Mo Mu*	Postdoc
George Vanecek	Postdoc
Panos Papachiou*	Software Engineer
Nicholas Chrisochoides*	Ph.D. candidate
Sanjiva Weerawarana*	Ph.D. candidate
Ko Yang Wang*	Postdoc
Sang Bae Kim	Ph.D. candidate
Scott McFadden	Ph.D. candidate
Jing Yu Liao	Ph.D. candidate
T. Ku	Ph.D. candidate (Civil Engineering)
Hyeran Byun	Ph.D. candidate
Pelayia Varodoglu	M.S. candidate
Jim Berniger	M.S. candidate
Athanasios Gaitatzes	M.S. student
Margaret Gaitatzes	M.S. student
Meletis Samartzis*	Visiting Research Associate
Stavros Kortesis	Visiting Scholar

Those names with stars have received some direct AFOSR support, the others have research support from related projects.

Publications

We list the publications that have resulted from the past three years of work supported by the AFOSR. These include:

5 Books edited
7 Journal papers
11 Papers submitted for journal publication
18 Conference papers
11 Technical reports

Some of the technical reports contain work that will be submitted to journals or conferences.

A. Books

1. E.N. Houstis, J.R. Rice and R. Vichnevetsky, (editors), *Intelligent Mathematical Software Systems*, North-Holland, Amsterdam, (1990), 363 pages.

2. E.N. Houstis and D. Gannon, (editors), *Supercomputing 1989*, ACM Press (1989), 323 pages.

3. E.N. Houstis, J.R. Rice and R. Vichnevetsky, (editors), *Expert Systems for Scientific Computing*, North-Holland, Amsterdam, (1991), to appear.

4. E.N. Houstis and Y. Muraoka, (editors), *Supercomputing 1991*, ACM Press (1991), 359 pages.

5. E.N. Houstis and John R. Rice, (editors), *IMACS volume AI, Expert Systems and symbolic Computing for Scientific Compution*, North-Holland, Amsterdam, (1992), to appear.

B. Papers and Reports

6. E.N. Houstis and J.R. Rice, Parallel ELLPACK, *Math. Comp. Simulation*, **31**, (1989), 497–508.

7. E.N. Houstis and J.R. Rice, The engineering of modern interfaces for PDE solvers, *Proceedings of IMACS World Congress*, Dublin (1991).

8. A. Chen and J.R. Rice, On grid refinement at point singularities for h-p methods, *Intl. J. Numer. Math. Engin.*, to appear.

9. M. Mu and J.R. Rice, A grid based subtree-subcube assignment strategy for solving PDEs on hypercubes, *SIAM J. Sci. Stat. Comp.*, to appear.

10. A. Hadjidimos, E.N. Houstis, J.R. Rice and E.A. Vavalis, Iterative line cubic spline collocation methods for elliptic partial differential equations in several dimensions, *SIAM J. Sci. Stat. Computing.*

11. A. Hadjidimos and A.K. Yeyios, Some recent results on the modified SOR theory, *Journal of Linear Algebra and Applications*, 154-156 (1991), 5–21.

12. A. Hadjidimos and M. Neumann, Convergence domains of the SSOR method for generalized consistently ordered matrices, *Journal of Computational and Applied Mathematics*, 33 (1990), 35–32.

13. M. Mu and J.R. Rice, Row oriented Gauss elimination on distributed memory multiprocessors, *submitted for publication.*

14. D.C. Marinescu and J.R. Rice, On single parameter characterization of parallelism. Proceedings of IEEE Frontiers '90 conference, October 1990. *Expanded version submitted to a journal.*

15. A. Hadjidimos, A. Psimarni and A.K. Yeyios, On the convergence of the modified accelerated overrelaxation (MAOR) method, *Applied Numerical Mathematical* (accepted for publication).

16. A. Hadjidimos, S. Galanis, D. Noutsos and M. Tzoumas, On the optimum relaxation factor associated with p-cyclic matrics, *Linear Algebra and its Application*, (in press).

17. A. Hadjidimos and Y.G. Saridakis, Modified successive overrelaxation (MSOR) and equivalent 2-step iterative methods for collocation matrices, *Journal of Computational and Applied Mathematical*, (accepted for publication).

18. C.E. Houstis, E.N. Houstis, S. M. Samartzis, J.R. Rice and D. Alexandrakis, The algorithm mapper II: A system for modeling and evaluating parallel applications/architecture pairs, *submitted for publication.*

19. N.P. Chrisochoides, C.E. Houstis, E.N. Houstis, S.K. Kortesis, and J.R. Rice, Automatic load balanced partitioning strategies for PDE computations, in *Supercomputing 1989*, ACM Press (1989), 99–107.

20. A. Hadjidimos, E.N. Houstis, J.R. Rice, M. Samartzis, and E.A. Vavalis, Semi-iterative methods on distributed memory multiprocessor architectures, in *Supercomputing 1989*, ACM Press (1989), 82–90.

21. C.E. Houstis, E.N. Houstis, J.R. Rice, S.M. Samartzis, and D.L. Alexandrakis, The algorithm mapper: A system for modeling and evaluating parallel application/architecture pairs, in *Intelligent Mathematical Software Systems*, North-Holland (1989), 87–101.

22. D.C. Marinescu and J.R. Rice, Multilevel asynchronous iterations for PDEs, in *Iterative Methods* (D. Kincaid, ed.), Academic Press (1990), 193–213.

23. J.R. Rice, Libraries, software parts and problem solving systems, in *Symposium on Scientific Software* (Cai, Fosdick, Huang, eds.), Tsinghua Univ. Press, Beijing (1989), 191–203.

24. D.C. Marinescu and J.R. Rice, Synchronization and load imbalance effects in distributed memory multiprocessor systems. Accepted for the 23rd Allerton Conference, October 1990.

25. D.C. Marinescu, J.R. Rice, B. Waltsburger, C.E. Houstis, T. Kunz, and H. Weldschmidt, Distributed Supercomputing, in *Future Trends '90*, IEEE Press, (1990), 381–387.

26. E.N. Houstis, M. Katzouraki, T.S. Papatheodorou and V. Sotiropoulou, Logical parallelism in an expert system for solving partial differential equations, in *Intelligent Mathematical Software Systems*, North Holland (1989), 111–123.

27. E.N. Houstis, J.R. Rice, N. Chrisochoides, H. Karathanasis, P. Papachiou, M. Samartzis, E. Vavalis and K. Wang, //ELLPACK: A numerical simulation programming environment for parallel MIMD machines. In *Supercomputing 90*, ACM Press (1991), 96–107.

28. N. Chrisochoides, C.E. Houstis, E.N. Houstis, P.N. Papachiou, S. Kortesis and J.R. Rice, Domain decomposer: a software tool for partitioning PDE computations baseed on geometry based mapping strategies. In *Domain Decomposition Methods*, SIAM Press (1991), 341–357.

29. D.C. Marinescu, J.R. Rice and E. Vavalis, Performance of iteration methods for distributed memory processors. CSD-TR-979, Computer Science Department, Purdue University, May (1990). Proceedings of 3rd IMACS World Congress, (1991).

30. S. Weerawarana, E.N. Houstis and J.R. Rice, An interactive symbolic-numeric interface to parallel ELLPACK for building general PDE solvers. *Proceedings of the Integration of Numeric and Symbolic Computing*, Saratoga Springs, July (1990), to appear.

31. M. Mu and J.R. Rice, Performance of PDE sparse solvers on hypercubes, to appear in *Unstructured Scientific Computations on Scalable Multiprocessors*, MIT Press, (1991), to appear.

32. C.E. Houstis, E.N. Houstis, T. Papatheodorou, J.R. Rice, and P. Varodoglou, ATHENA: A knowledge base system for //ELLPACK. CSD-TR-950, Computer Science Department, Purdue University, February (1990). Accepted for Intl. Conf. on Symbolic and Numeric Methods, Paris, September (1991).

33. H.S. McFaddin and J.R. Rice, A software platform for relaxation, in *Intelligent Scientific Software Systems*, North-Holland (1991), to appear.

34. J. R. Rice, R. Vichnevetsky, and E.N. Houstis, Second international conference on expert systems for numerical computing. CSD-TR-963, Computer Science Department, Purdue University, March (1990).

35. D.C. Marinescu and J.R. Rice, Application of the E/T performance modeling methodology to a computation on a 128 Processor NCUBE. CSD-TR 998, Computer Sciences Department, Purdue University, July (1990).

36. A. Hadjidimos and Y.G. Saridakis, Modified successive overrelaxation (MSOR) and equivalent 2-step iterative methods for collocation matrices. CSD-TR-965, Computer Science Department, Purdue University, March (1990).

37. M. Mu and J.R. Rice, PARALLEL SPARSE: Data structure and organization. CSD-TR-974, Computer Science Department, Purdue University, April (1990).

38. M. Mu and J.R. Rice, The structure of parallel sparse matrix algorithms for solving partial differential equations on hypercubes. CSD-TR-976, Computer Science Department, Purdue University, April (1990).

39. E.N. Houstis, S.K. Kortesis and H. Byun, A workload partitioning strategy for PDEs by a generalized neural network. CSD-TR-934, Computer Science Department, Purdue University, May (1990). Presented in the IJCNN for Neural Network Conference, July 1991.

40. A. Hadjidimos, E.N. Houstis, J.R. Rice and E.N. Vavalis, On the iterative solution of line spline collocation schemes for elliptic PDEs. CSD-TR-768, Computer Science Department, Purdue University, May (1990).

41. M.P. Chrisochoides, E.N. Houstis and C.E. Houstis, Geometry based mapping strategies for PDE computations, CAPO-90-16, Computer Sciences, Purdue University, (1990). Proceedings of Supercomputing 1991, ACM Press (1991)

42. E.N. Houstis and J.R. Rice, Parallel (//) ELLPACK PDE solving system. CSD-TR-912, Computer Science Department, Purdue University, October (1989).

43. K.Y. Wang, A framework for intelligent parallel computers, CAPO Report CER-90-52, Nov. (1990). Submitted to International Conference on Supercomputing 1991.

44. K.Y. Wang, Array reshaping – a mechanism for optimizing array storage on parallel architectures, CAPO Report CER-90-44, Dec. (1990).

45. K.Y. Wang, Managing data synchronization automatically for distributed-memory architectures, CAPO Report CER-90-45, Dec. (1990).

46. K.Y. Wang, Heuristic guided pre-optimized algorithm substitution for parallel computers, CAPO Report CER-90-50, Dec. (1990).

47. K.Y. Wang, D. Gannon and P. Mehrotra, Machine knowledge manipulation issues for parallel compilers, CAPO Report CER-90-51, Dec. (1990).

48. N.P. Chrisochoides, M. Aboelaze, C.E. Houstis, E.N. Houstis, The parallelization of some level 2 and 3 BLAS operations on distributed memory machines, Proceeding of the Austria conference on parallel computing, Oct. 1991.

49. E.N. Houstis and J.R. Rice, Parallel ELLPACK: A development and problem solving environment for high performance computing machines, Proceedings of the IFIP TC 2 working conference on "programming environments for high-level scientific problem solving", North-Holland, Amsterdam, (1992) to appear.

50. S. Galanis and A. Hadjidimos, How to repartition a block p-cyclic consistently ordered matrix for optimal SOR convergence, *SIAM J. Math. Anal. Appl.* (to appear in Jan. 1992).

51. A. Hadjidimos, E.N. Houstis, J.R. Rice and E.A. Vavails, CAPO report, CER-91-09 (1991).

52. A. Hadjidimos, A. Psimarni, Y.G. Saridakis and A. K. Yeyios, The block modified successive overrelaxation (MAOR) method for generalized consistently ordered matrices, CAPO report CER-90-36 (1990).

53. A. Hadjidimos and D. Noutsos, On a matrix identity connecting iteration operators associated with a p-cyclic matrix, CAPO report CER-91-25 (1991).

C. Conference Involvement of PIs

We list those conference presentations made personally by the PI's (E. Houstis and J. Rice) and recap their involvement in organizing conferences and workshops. Other conference presentations were made by co-authors; these are not listed here.

PAPERS PRESENTED

Paper 21 was presented at the conferences: (a) *IMSL User's Group-North America*, Ann Arbor, May 1989; (b) *Symposium on Scientific Software*, Beijing, China, June 1989. (Rice)

Papers 4 and 25 presented at the (a) *International Conference on Supercomputing*, Amsterdam, June 1990, (b) Workshop on the Integration of Numeric/Symbolic Computing, Saratoga Springs, July 1990, (c) DARPA Workshop on *Scalable Parallel Libraries*, September 1990, (d) Workshop on European Supercomputers ESPRIT project GENESIS, Barcalona and Bonn, May 1990, (Houstis), (e) IMSL User's Group - Europe, Bologna, Italy, March 27, 1990, (f) University of L'Aguila, March 30, 1990. (Rice)

Paper 25 was presented at the *Domain Decomposition* conference, Moscow, May 1990. (Houstis)

Paper 27 was presnted in the European ESPRIT project Pygmilian on Neural Computing, London, U.K., June 1990. (Houstis)

Paper 37 was presented in the Congress on Computation and Applied Mathematics, Belgium, June 1990. (Houstis)

Paper 31 was presented at the Second International Conference on Expert Systems for Numerical Computing, W. Lafayettte, IN, April 1990. (Rice)

Papers 17 and 18 were presented at the International Conference on Supercomputing, St. Malo, France, June 1989. (Houstis)

Paper 19 was presented at the International Conference on Expert Systems for Numerical Computing, W. Lafayette, IN, December 1988. (Houstis and Rice)

Paper 20 was presented at the conference on Iterative Methods for Large Linear Systems, Austin, TX, October 1988. (Rice)

Paper 28 was presented at the conference on the Integration of Numeric and Symbolic Computing, Saratoga Springs, July 1990. (Houstis).

Paper 29 was presented at the conference on Unstructured Scientific Computations on Scalable Multiprocessors, Nags Heads, NC, October 1990. (Rice).

Paper 31 was presented at the Paris conference on Symbolic and Numeric Methods (Rice)

Paper 40 was presented at the International Conference on Supercomputing, Kologne, Germany, June 1991. (Houstis)

Paper 48 will be presented at the IFIP TC 2 working conference, Karlsruhe, Germany, Sept. 1991. (Houstis)

Paper 7 was presented in the 3rd IMACS World Congress, Dublin 1991.

OTHER CONFERENCE PRESENTATIONS

J.R. Rice, Collaborating Modules for Solving PDEs, Seventh International Conf. on Modeling and Simulation, IMACS, August 1989.

J.R. Rice, Domain Processing and Manipulation. Invited talk. SIAM Conference on Geometric Design, Tempe, Arizona November 1989.

J.R. Rice, The Effects of Communication Latency Upon Synchronization and Dynamic Load Balance on a Hypercube, International Parallel Processing Symposium, Anaheim, CA, April 1991. IEEE Press, (1991), 18–25.

J.R. Rice, Symposium to Honor G. Birkhoff's 80th birthday, June 28, Cambridge, MA. Collaborating PDE Solvers, by H.S. McFaddin and J.R. Rice.

J.R. Rice, IMSL User's Group-Japan, July 3-4, Tokyo. Massive Parallelism for Computational Models of Physical Objects.

CONFERENCE AND WORKSHOP ORGANIZATIONS

E. Houstis, Member of Program Committee for International Supercomputing Conferences 1990 and 1991.

E. Houstis, Chairman of the Program Committee for North American region, International Conference on Supercomputing 1991.

E. Houstis and J. Rice, Co-Chairmen of the First (1988) and Second (1990) International Conference on Expert Systems For Scientific Computing.

E. Houstis, Member of the Programming Committee and Editor of the IFIP WG2.5 Conference on Programing Environments for High-Level Scientific Problem Solving, Germany, September 1991.

J. Rice, Member of the Program Committee of the IFIP WG2.5 Conference on Programming Environments for High-Level Scientific Problem Solving, Germany, September 1991.

E. Houstis and J. Rice, Organizing committee of NSF Worskhop on Future Research Trends in Combined Numerical, Symbolic, Geometric and Logical Methods in Scientific Computing, Washington, D.C., April 1991.

E. Houstis and J.Rice, Organizing a Session on "Expert Systems for Parallel Computing", in the IFIP World Congress, Dublin 1991.

E. Houstis program committee chairman for North America and editor of the International Conference for Supercomputing, Kologne, Germany 1991.